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# THERMAL ANALYSIS OF SOLID DISC BRAKE ROTOR

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***ABSTRACT***

***The work deals with the analysis of heat generation and dissipation in a solid disc brake of a motorcycle during continuous braking by using computer -aided engineering software with two disc profile and three different materials of the rotor disc. The objective of this work is to investigate and analyze the temperature distribution and heat dissipation (steady- state thermal analysis) of the rotor disc during braking operation. The work uses the finite element analysis technique to predict the temperature distribution on the disc rotor and to identify the critical temperature of the brake rotor disc. All three modes of heat transfer (conduction, convection, radiation) have been analyzed. The three different materials studied are Grey Cast Iron, Aluminum Alloy 6262 T-9 and Carbon-Ceramics with two different profiles of disc rotor. The results obtained from the analysis shows that different material on similar load conditions during continuous braking shows different temperature distribution. Thus, a comparison is made between the three materials used to know the best material for making disc brake rotor based on the rate of heat dissipation and critical temperature. Hence, it is found that Aluminum Alloy is the most appropriate material among all three material selected for solid disc rotor.***

***KEYWORDS: CATIA, ANSYS, Disc Brake, Critical Temperature, Heat Dissipation & Disc Profile***

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**Original Article**

## INTRODUCTION

A braking system is said to be a one of the most important safety components of an automobile. It is mainly used to decelerate the vehicles speed from an initial speed to a given speed (Book, W.J., 1990). The controlling of a brake is the brake pedal, controlled by the driver with a foot. Under extreme conditions, such as descending a steep hill with a heavy load, or repeated high-speed decelerations, drum brakes would often fade and lose its performance and lose its effectiveness. Compared with their counterpart, hence disc brakes would operate with less fade under the same conditions. Excessive thermal loading can result in surface cracking, judder and a high wear of the rubbing surfaces. The rise of High temperatures can also lead to overheating of brake fluids, seals and other components [14].

The disc brake is a device used for slowing or stopping the rotation of the wheel. The disc brake is usually made of cast iron, aluminum alloy, stainless steel, carbon ceramic, is connected to the wheel and/or axle. To stop the vehicle, friction material in the form of brake pads (mounted on a device called brake caliper) is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of disc rotor [15]. Friction material causes the disc rotor along with wheel to slow or stop by rubbing action. The energy absorbed leads to

rising in temperature of disc rotor. This heat is dissipated into the surrounding atmosphere to stop the vehicle [1]. The greater the pressure applied, the more friction and heat produced, the sooner the vehicle is brought to stop [6]. So the brake system should have the following requirements: The brakes must be strong enough to stop the vehicle within the minimum distance in an emergency. The driver must have proper control over the vehicle during braking and vehicle must not skid. The brakes must have well anti-fade characteristic, i.e. their effectiveness should not decrease with the constant prolonged application. The brakes should have good antiwear properties [20]. Therefore, for effective braking conditions suitable material has to be considered at the design stage itself, for the disc rotor and brake pad based on strength, wear resistance, heat dissipation rate and load capacity of the vehicle [7].

The objective of this paper is to design the solid disc rotor cross drilled with large number of holes and with inclined row of slotted disc to specifications by using CATIA V5. To perform thermal analysis of both above specified profiles for critical temperature rise and the heat dissipation rate on different materials, using ANSYS R14.5. Best combination of parameters of a disc brake rotor profile and rotor material is to be suggested.

### Disc Brake

A disc brake consists of a cast iron disc rotor bolted to the wheel hub and a stationary housing called a caliper. The caliper is connected to the stationary part of the vehicle like the axle casing or the stub axle as is cast in two parts each part containing a piston. In between each piston and the disc, there is a friction pad held in position by retaining pins, spring plates, etc. Passages are drilled in the caliper for the fluid to enter or leave each housing. The passages also connect to another one for bleeding. Each cylinder contains rubber- sealing ring between the cylinder and piston. [9].

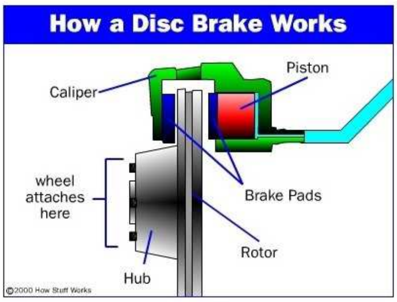


**Figure 1: Working of Disc Brake**

## MODELING OF DISC ROTOR

### Introduction

CATIA V5 is mechanical design software, addressing advanced process -centric design requirements of the mechanical industry. With its feature- based design solutions, CATIA proved to be highly productive for mechanical assemblies and drawing generation. CATIA, with its broad range of integrated solutions for all manufacturing organizations. CATIA is the best solution capable of addressing the complete product development process, from product concept specification through product service in a fully integrated and associative manner.

- Sketcher
- Part design.
- Assembly design.

- Wireframe and surface design.
- Drafting.

**Drafting (Cad Model)**

Drawings and documentation are the true products of design because they guide the manufacture of a mechanical device. CATIA automatically generates associative drafting from 3D mechanical designers and assemblies. Associability of the drawings to the 3D master representation enables to work concurrently on designs and drawings. CATIA enriches Generative Drafting with both integrated 2D interactive functionality and a productive environment for drawing dress-up and annotation.

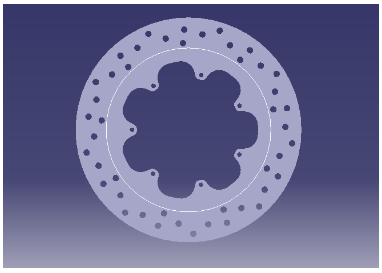

**Figure 2: Cross Drilled Disc with Number of Holes**

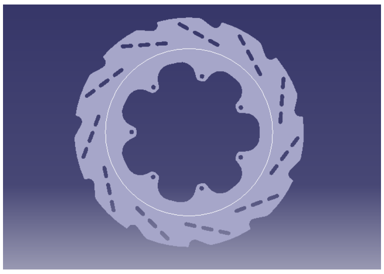

**Figure 3: Inclined Row of Slotted Disc**

**Finite Element Method (FEM)**

It is a numerical technique for finding the approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into the simpler part, called finite elements and solve the problem by minimizing an associated error function. The subdivision of the whole domain has several advantages:

- Accurate representation of the complex geometry.
- Inclusion of dissimilar material property.
- Easy representation of the solution.
- Capture of the local effects.

It divides the domain into a group of subdomain; every subdomain is represented by a set of element equations of the original domain.

## MATERIALS USED FOR DISC BRAKE

**Cast Iron**

Metallic iron containing Carbon 2 to 5%, Silicon 1 to 3%, but may also contain a small percentage of Sulfur, Manganese and Prosperous within its matrix is referred to as gray cast iron because of its characteristic color. Considering its cost, relative ease of manufacture and thermal stability, this cast iron (particularly, gray cast iron), is actually a more specialized material for brake applications particularly the material of choice for almost all automotive brake discs. To work correctly, the parts must be produced at the foundry with tightly monitored chemistry and cooling cycles to control the shape, distribution, and form of the precipitation of the excess carbon. This is done to minimize distortion in machining, provide good wear characteristics, dampen vibration and resist cracking in subsequent use. The cast-iron disc is

the heaviest of all types and also has a disadvantage information of rust. They usually range from 6-8 kgs for each disc of a car. But they are still preferred for high powering vehicles.

**Aluminum Alloy**

Aluminum alloys are used in advanced applications because of high strength, low density, durability, machine ability, availability, and cost are very attractive compared to competing materials. The aluminum metal matrix composite materials are the combination of two or more constituents in which one is matrix and other is filler materials (reinforcements). The Aluminum metal matrix may be laminated, fibers or particulate composites. Generally, grey cast iron is used to manufacture brake disc rotor, but AMMC is selected considering crucial advantages of the AMMC over cast iron material. Disc brake used for decelerating or stopping the automobile or to maintain a constant velocity or to park the vehicle. This specification dictates the correct range of hardness, chemical composition, tensile strength and other properties necessary for the intended use. Aluminum alloy discs are light, they were less resistant to heat and fade. Aluminum is a better rotor material than cast iron due to two main reasons:

- Its density is as one third as cast iron.
- Its thermal conductivity is three times greater.

These factors made it possible to construct a much lighter brake disc.

**Carbon Ceramic**

Ceramics are inorganic, non-metallic materials that are processed and used at high temperatures. They are generally hard, brittle materials that withstand compression very well, but do not hold up well under tension compared to the metals. They are abrasive resistant, heat resistant (refractory) and can sustain large compressive loads even at high temperatures. The nature of the chemical bond in the ceramics is generally ionic in character, and the anions play an important role in the determination of the properties of the material. The typical anions present is carbides, borides, nitrides and oxides. The different types of ceramics are clays, refractoriness, glasses etc.

Ceramic brake discs are 50% lighter than metal brake discs. As a result, they can reduce the weight of the vehicle by up to 20kg and apart from saving fuel, this also means a reduction in unsprung masses. The ceramic brake disc ensures very high consistent frictional values throughout the entire deceleration process. With Porsche ceramic brake discs, a car was able to decelerate from 100Km to 0Km in less than 3 seconds. Ceramics retain their resistance up to 2000 degree Celsius. Only if the temperature is excess of this, they lose their dimensional stability. They are not subject to wear, are maintenance free and are heat and rust resistance. Heavy commercial vehicles can be braked safely over long distances without having to undergo brake maintenance. This dispenses with the need for expensive maintenance. Dry and wet performances are excellent. Ceramics are waterproof materials and the brake pads always remain dry.

The main disadvantage of ceramic brake discs is their high initial cost. Initially the ceramic matrix composite brake discs will be more expensive than the current technology metal ones due to lower manufacturing volumes and high cost of production. But, because of the advantages listed above, the ceramic brakes will work out to be cheaper in the long run.

## MATERIAL PROPERTIES

**Table 1: Material Properties**

| | Grey Cast Iron | Aluminum Alloy 6262 T-9 | Carbon-Ceramic |
|---|---|---|---|
| Density ($kg/m^3$) | 7200 | 2800 | 2450 |
| Elastic Modules (Gpa) | 110 | 68 | 30 |
| Poisson's ratio | 0.28 | 0.33 | 0.27 |
| Thermal Conductivity (w/m k) | 54 | 170 | 40 |
| Specific Heat ($J/kg^o c$) | 500 | 890 | 800 |
| Coefficient of thermal expansion ($10^{-6}$ $k^{-1}$) | 10.5 | 23 | 2.8 |

## INPUT PARAMETERS & THEORETICAL CALCULATIONS

### Input Parameters

- Mass of the vehicle (m) = 200kg
- Initial velocity (u) = 22.22m/s (80kmph)
- Vehicle speed at end of brake application (v) =0 m/s
- Load on front wheel = 50%
- Kinetic energy absorbs by disc rotor (δ) = 80%
- Acceleration due to gravity (g) = 9.81m/s
- Diameter if Disc rotor = 240mm
- Thickness of Disc rotor = 3.5mm

### Theoretical Calculations

- **Energy Generated during Braking**

  $K.E = \delta \times 0.5 \times \frac{m(u)^2}{2}$

  $= 0.8\times 0.5 \times \frac{200\times 22.22^2}{2}$

  = 19749.13 Joule

- **To Calculate Deceleration Time**

  v= u + at

  Deceleration time = braking time = 6sec

- **Braking Power**

  $P_b = \frac{K.E}{t} = \frac{19749.13}{6} = 3291.52$ watts

- **Heat Flux**

$Q= \frac{Pb}{A}$

Hear A, is the rubbing area on disc rotor $=2\times\pi\ (0.11^2 - 0.0925^2) = 0.02226\text{m}^2$

$Q = \frac{3291.52}{0.02226} = 147826.92\ \text{w/m}^2$

**Calculations for Input Parameters**

**Table 2: Calculations for Input Parameters**

| | Formula | Grey Cast Iron | Aluminum Alloy 6262 T-9 | Carbon-Ceramic |
|---|---|---|---|---|
| Kinetic Energy | $K.E = \delta x 0.5x \frac{m(u)^2}{2}$ | 19749.13 Joule | 19749.13 Joule | 19749.13 Joule |
| Braking time | v= u + at | 6 sec | 5.5 sec | 5 sec |
| Braking power | $P_b = \frac{K.E}{t}$ | 3291.52watts | 3590.75watts | 3949.82watts |
| Heat flux | $Q= \frac{Pb}{A}$ | 147826.92 w/m$^2$ | 161265.82 w/m$^2$ | 177392.40 w/m$^2$ |

## RESULTS

**Grey Cast Iron**

**Model 1: Disc Rotor with Holes**

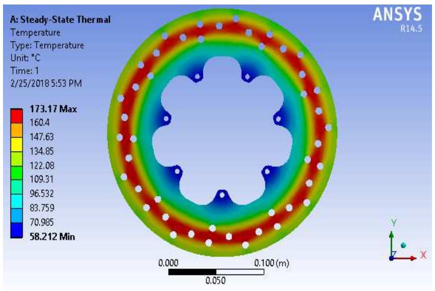


Figure 4: Temperature Distribution for Grey Cast Iron

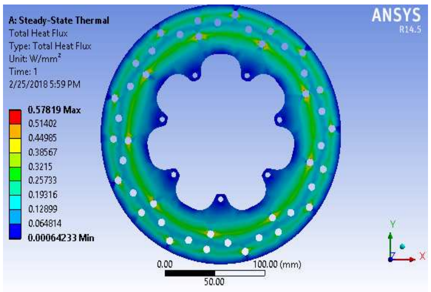


Figure 5: Heat Flux Plot for Grey Cast Iron

**Model 2: Disc Rotor with Slots**

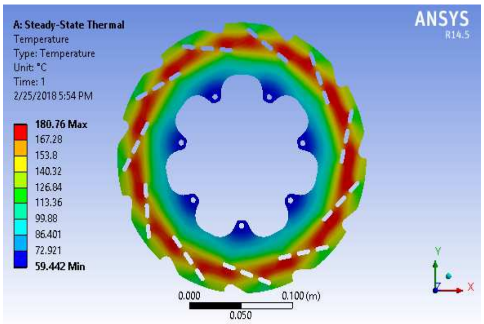


Figure 6: Temperature Distribution for Grey Cast Iron

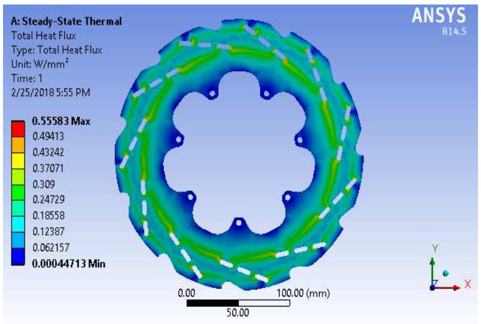


Figure 7: Heat Flux Plot for Grey Cast Iron

**Aluminum Alloy 6262 T-9**

**Model 1: Disc Rotor with Holes**

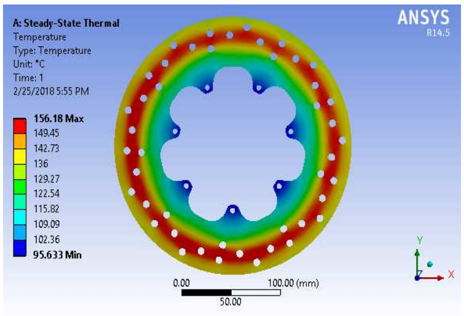


**Figure 8: Temperature Distribution for Aluminum Alloy 6262 T-9**

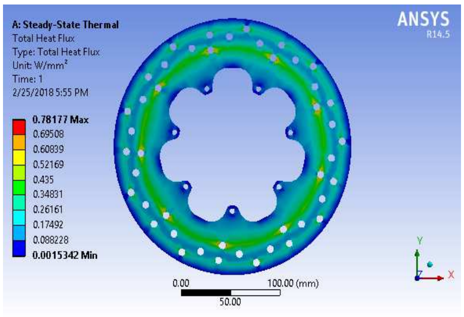


**Figure 9: Heat flux plot for Aluminum Alloy 6262 T-9**

**Model 2: Disc Rotor with Slots**

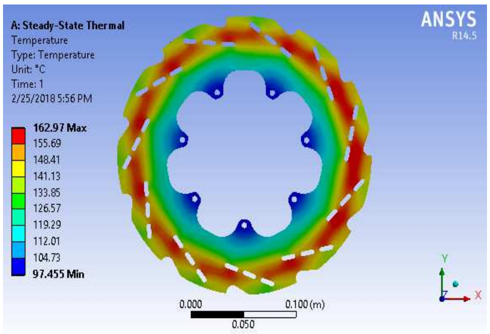


**Figure 10: Temperature Distribution for Aluminum Alloy 6262 T-9**

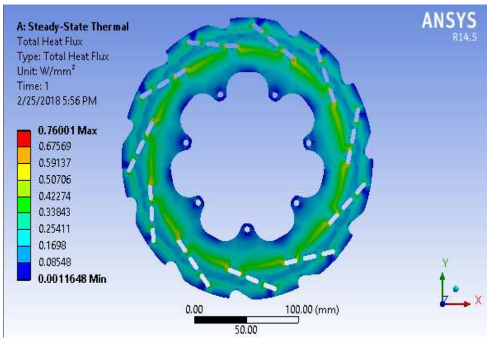


**Figure 11: Heat Flux Plot for Aluminum Alloy 6262 T-9**

**Carbon Ceramic**

**Model 1: Disc Rotor with Holes**

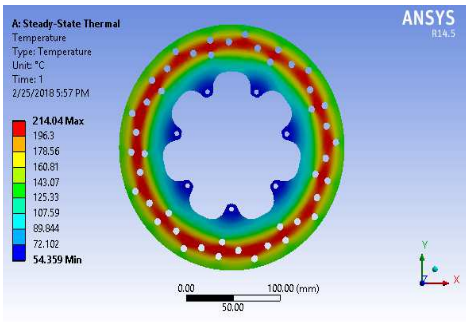


**Figure 12: Temperature Distribution for Carbon Ceramic**

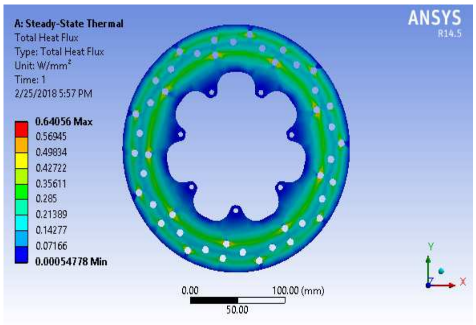


**Figure 13: Heat Flux Plot for Carbon Ceramic**

**Model 2: Disc Rotor with Slots**

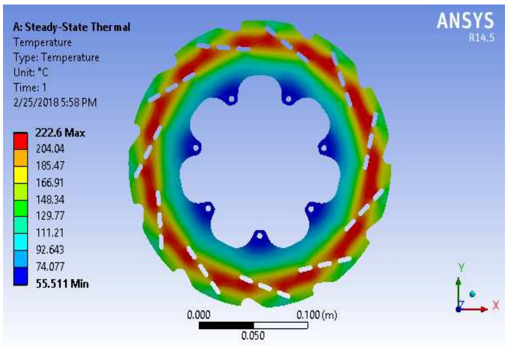


**Figure 14: Temperature Distribution for Carbon Ceramic**

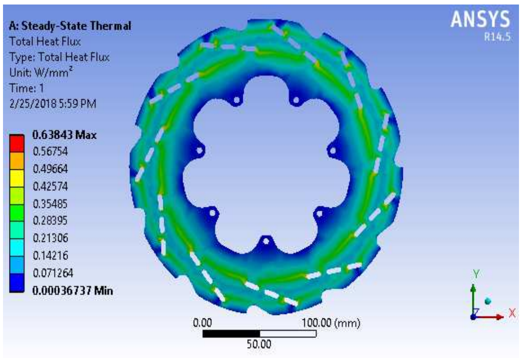


**Figure 15: Heat Flux Plot for Carbon Ceramic**

## COMPARISON TABLE

**Table 3: Comparison Table**

| Materials | | Grey Cast Iron | | Aluminum Alloy 6262 T-9 | | Carbon-Ceramic | |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max |
| Temperature Distribution ( $^{o}$C ) | Model No.1 | 58.21 | 173.17 | 95.63 | 156.18 | 54.35 | 214.04 |
| | Model No.2 | 59.44 | 180.76 | 97.45 | 162.97 | 55.51 | 222.60 |
| Total Heat Flux ( W/mm$^2$ ) | Model No.1 | 0.64e-3 | 0.5781 | 0.15e-2 | 0.7817 | 0.54e-3 | 0.6405 |
| | Model No.2 | 0.44e-3 | 0.5558 | 0.11e-2 | 0.7600 | 0.36e-3 | 0.6384 |

## CONCLUSIONS

From our study of two disc profile for various materials to the maximum temperature rise observed for carbon-ceramic is 222.6$^{o}$C and for aluminum alloy 162.97$^{o}$C. The maximum temperature rise in cast iron is 180.76$^{o}$C which is less as compared to the carbon ceramic, hence it is preferred for moderate load applications. The carbon ceramic has the minimum weight of other materials and maximum temperature produce is highest as compare to other materials but it shows good heat dissipation rate. It is costly compared to other materials and cannot machined easily, So it can be used in racing cars where high temperature is produced. The aluminum alloy has the lowest maximum temperature rise with the greatest heat dissipation rate when compared to other materials. From the above table, the disc profile with the most number of holes has a best heat dissipation rate with least temperature rise. Comparing the above results obtained from the thermal analysis, it is concluded that aluminum alloy with cross drilled disc rotor is the best possible combination for the present application.

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